Testing Tensile and Shear Epoxy Strength at Cryogenic Temperatures

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Background

• In order to attach MLI blankets to spacecraft in a manner to survive a combination of acceleration, acoustic, and venting loads while minimize the parasitic heat load to the tank. The attachments serve as direct heat loads to the tank and often are a significant portion of a tank applied heat load [1]. There have been instances where MLI was not appropriately attached to spacecraft and has been lost or damaged, compromising the mission. [2, 3]. Based on a review of typical attachment methods, most use plastic (nylon or ultem) holders to minimize conduction loss through a blanket. However, these plastics have a much larger coefficient of thermal contraction and often contract 1% or more than most base metals [4]. As such, an epoxy must be able to handle the differential contraction between the two materials and also handle the many other forces that it may encounter.

• A typical insulation system for a cryogenic upper stage would include spray-of foam insulation (SOFI) underneath the MLI blankets to prevent air liquefaction. The polyether-imide standoffs would be attached to the tank and protrude through the SOFI to provide points of attachment for the MLI blankets. Previous attempts to attach the MLI directly to SOFI has induced cracking in the SOFI as shown in • Figure 1 [5].

• For reference, Figure 2 shows a possible configuration of a standoff with an MLI blanket. The flat, disk portion of the standoff is bonded to the tank wall with epoxy. The strength of that epoxy bond at cryogenic temperatures is important since failure of that bond would cause the MLI to separate from the tank and increased the boil-off of cryogenic propellants. Therefore tests were conducted to assess the tensile and shear epoxy strength to aluminium, primed aluminium, and stainless steel samples at cryogenic temperatures.

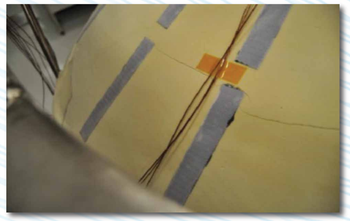


Figure 1. SOFI after MLI was directly attached to the surface.

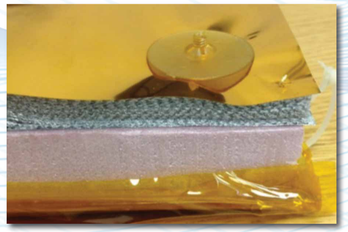
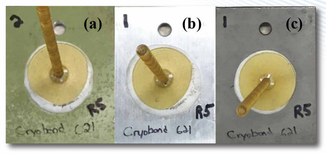


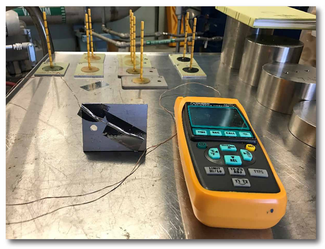
Figure 2. An MLI standoff holding the MLI blanket and foam insulation to the metal surface.

Coupon Preparation and Cooling

15 Epoxies (65 coupons) tested in tensile and shear over the last 8 months.



Sample coupons
(a) Primed 2195 aluminium sample.
(b) Aluminium 6061 sample.
(c) Stainless steel 304 sample.



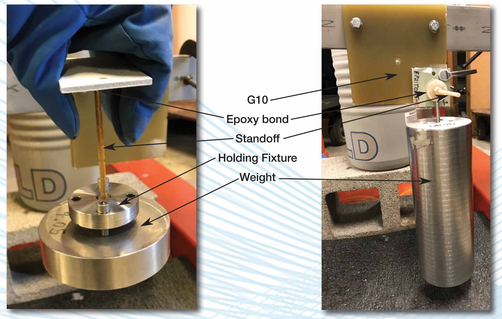
Thermocouple Attachment



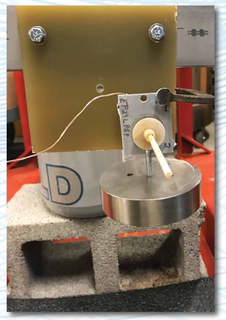
Coupon Cooling over LN2 Dewar

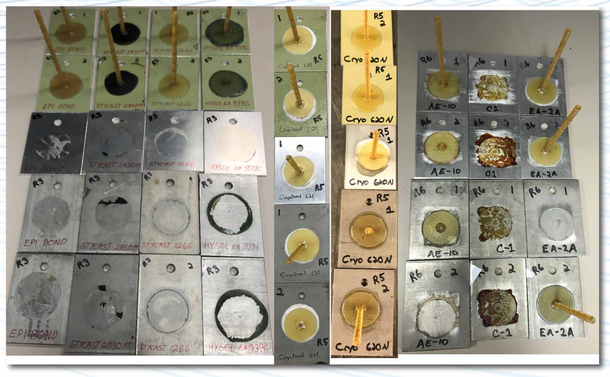
Coupon Tensile and Shear Testing Method

Pull Tests



Shear Tests





Round 3, 5, and 6 coupons after testing

Coupon Tensile and Shear Testing Method

Successful Test
X Epoxy Failure
Standoff Break
Popping Noises While Cooling
Sound Observations Not Recorded

Epoxy Brand		Coupon Material	Trial	Popping	Cryogenic Tensile Epoxy Testing (Mass, kg (Samples maintained at approx. 86 K)) 1.3	2.0	3.6	5.3	6.9	8.0	10.5	11.8	16.0	18.5	Cryogenic Shear Epoxy Testing (Mass, kg (Samples maintained at approx. 86 K)) 1.1	1.8	3.4	5.1	6.7	7.8	10.3	11.6	15.9	18.3
Allbonn	C1	AL - 6061	1	*	✓	✓	✓	✓	✓	✓	✓	✓	X Epoxy failure											
			2	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X EF
		SST 304	1	*	✓	✓	X Epoxy failure																	
			2	*	X Epoxy failure																			
	EA-2A	AL - 6061	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		SST 304	1		X Epoxy failure																			
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CTD	621	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		SST 304	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	Standoff break											
GE	Varnish	AL - 2219 primered	1	**	X Epoxy failure																			
		AL - 6061	1		X Epoxy failure																			
		SST 304	1		X Epoxy failure																			
Hardman	EPBond	AL - 2219 primered	1	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1	*	X Epoxy failure																			
		SST 304	1	*	X Epoxy failure																			
			2	*	✓	X Epoxy failure																		
HYSOL	EA 9430	AL - 2219 primered	1	**	X Epoxy failure																			
		AL - 6061	1	**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		SST 304	1		X Epoxy failure																			
	EA 9309	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	Standoff break											
		AL - 6061	1	*	X Epoxy failure																			
		SST 304	1		✓	X Epoxy failure																		
			2		X Epoxy failure																			

Epoxy Brand		Coupon Material	Sample #	Popping	Cryogenic Epoxy Strength Testing (Coupons maintained at approx. 86 K) Tensile (kg)	Shear (kg)
Allbonn	C1	AL - 6061	1	*	16.0 X	-
			2	*	✓	18.3 X
		SST 304	1	*	3.6 X	-
			2	*	1.3 X	-
	EA-2A	AL - 6061	1		✓	✓
			2		✓	✓
		SST 304	1		1.3 X	-
			2		✓	✓
CTD	621	AL - 2219 primered	1		✓	✓
			2		✓	✓
		AL - 6061	1		✓	✓
		SST 304	1		✓	✓
			2		11.8 •	-
GE	Varnish	AL - 2219 primered	1	**	1.3 X	-
		AL - 6061	1	**	1.3 X	-
		SST 304	1		1.3 X	-
Hardman	EPBond	AL - 2219 primered	1	*	✓	✓
			2	*	✓	✓
		AL - 6061	1	*	1.3 X	-
		SST 304	1	*	1.3 X	-
			2	*	2.0 X	-
HYSOL	EA 9430	AL - 2219 primered	1		1.3 X	-
		AL - 6061	1	**	✓	✓
		SST 304	1		1.3 X	-
	EA 9309	AL - 2219 primered	1		✓	✓
			2		18.5 •	-
		AL - 6061	1	*	1.3 X	-
		SST 304	1		2.0 X	-
			2		1.3 X	-

Epoxy Brand		Coupon Material	Trial	Popping	Cryogenic Tensile Epoxy Testing (Mass, kg (Samples maintained at approx. 86 K)) 1.3	2.0	3.6	5.3	6.9	8.0	10.5	11.8	16.0	18.5	Cryogenic Shear Epoxy Testing (Mass, kg (Samples maintained at approx. 86 K)) 1.1	1.8	3.4	5.1	6.7	7.8	10.3	11.6	15.9	18.3
Masterbond	EP29LPSP	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	SB
			3		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		SST 304	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			3		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X Epoxy failure
	EP21TCHT-1	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	Standoff break															
	EP30-2	SST 304	1	**	X Epoxy failure																			
			2		X Epoxy failure																			
		AL - 2219 primered	1		✓	✓	✓	X Epoxy failure																
			2		✓	✓	X Epoxy failure																	
		SST 304	1		X Epoxy failure																			
			2		X Epoxy failure																			
	EA9133AHT-60	AL - 2219 primered	1		✓	✓	✓	X Epoxy failure																
			2		✓	X Epoxy failure																		
		SST 304	1		X Epoxy failure																			
			2		X Epoxy failure																			
Scotchweld	2216	AL - 2219 primered	1	**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1	**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		SST 304	1		✓	✓	✓	✓	✓	✓	Missing coupon													
3TSCAT	2850FT	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1	*	✓	✓	X Epoxy failure																	
		SST 304	1	*	✓	✓	X Epoxy failure																	
			2		✓	✓	X Epoxy failure																	
	1266	AL - 2219 primered	1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		AL - 6061	1		X Epoxy failure																			
		SST 304	1	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	X Epoxy failure										
			2		✓	✓	✓	✓	✓	✓	✓	✓	X Epoxy failure											

Epoxy Brand		Coupon Material	Sample #	Popping	Cryogenic Epoxy Strength Testing (Coupons maintained at approx. 86 K) Tensile (kg)	Shear (kg)
Masterbond	EP29LPSP	AL - 2219 primered	1		✓	✓
			2		✓	18.3 •
			3		✓	✓
		AL - 6061	1		✓	✓
		SST 304	1		✓	✓
			2		✓	✓
			3		✓	7.8 X
	EP21TCHT-1	AL - 2219 primered	1		✓	✓
			2		6.9 •	-
	EP30-2	SST 304	1	**	1.3 X	-
			2		1.3 X	-
		AL - 2219 primered	1		6.9 X	-
			2		5.3 X	-
		SST 304	1		1.3 X	-
			2		1.3 X	-
	EA9133AHT-60	AL - 2219 primered	1		5.3 X	-
			2		2.0 X	-
		SST 304	1		1.3 X	-
			2		1.3 X	-
Scotchweld	2216	AL - 2219 primered	1		✓	✓
		AL - 6061	1	**	✓	✓
		SST 304	1		✓	Missing coupon
3TSCAT	2850FT	AL - 2219 primered	1		✓	✓
			2		✓	✓
		AL - 6061	1	*	3.6 X	-
		SST 304	1	*	5.3 X	-
			2	*	5.3 X	-
	1266	AL - 2219 primered	1		✓	✓
			2		✓	✓
		AL - 6061	1		1.3 X	-
		SST 304	1	*	✓	1.11 X
			2		16.0 X	-

Conclusions/Results

- Best performance from **CTD CryoBond 621, Masterbond EP29LPSP,** and **Scotchweld 2216**
  – Passed tensile and shear testing for multiple coupon materials
- Sound indicators of epoxy and standoff failures
- 5 of 6 standoff failures occurred above 25lbs
- 24 of 65 samples survived tensile and shear testing (not including standoff breaks)

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